EARTHQUAKE WORKING GROUPS, DATABASE UPDATES, PALEOSEISMIC FAULT STUDIES, AND EARTHQUAKE-INDUCED LANDSLIDE HAZARD ASSESSMENT, UTAH

Award number: 03HQAG0008 (continuation)
January 1, 2004-December 30, 2004
Gary E. Christenson, Michael D. Hylland, William R. Lund,
Greg N. McDonald, and Christopher B. DuRoss
Utah Geological Survey
P.O. Box 146100
Salt Lake City, Utah 84114
Phone 801-537-3304, fax 801-537-3400, garychristenson@utah.gov
www.geology.utah.gov
Key words: regional seismic hazards, database, surficial deposits, Quaternary faults

INVESTIGATIONS UNDERTAKEN

The Utah Geological Survey (UGS), in cooperation with the U.S. Geological Survey (USGS) and Utah Seismic Safety Commission, convened a 2004 Earthquake Conference and second annual series of earthquake working group meetings in February 2004. In the working group meetings we revised the 2003 multi-year plans for developing the next generation of earthquake ground shaking, liquefaction, and earthquake-induced landslide maps for Utah, and held the final meeting of the Utah Quaternary Fault Parameters Working Group. In support of the working groups' effort, we updated our interactive Quaternary fault and fold, shallow shear-wave-velocity, deep-basin-structure, and geotechnical landslide shear-strength databases.

In addition, the UGS is mapping the surficial geology of the Fayette segment of the Wasatch fault zone as a continuation of USGS and UGS surficial geologic mapping of segments of the Wasatch fault. This mapping is used in paleoseismic characterization of the fault for both the UGS and USGS Quaternary fault databases used in the National Seismic Hazard Maps. We also began paleoseismic studies on the Sevier/Toroweap fault in southwestern Utah to identify likely sites for detailed study to determine the timing of the most recent surface faulting, possible segmentation, recurrence interval, and slip rate. We did not perform any additional earthquake-induced landslide studies.

RESULTS

Working Groups

The 2004 Utah Earthquake Conference was held on February 26, 2004, to present the latest results of mostly NEHRP-funded work over the previous year. Following the conference on February 27, 2004, one-day meetings of the Quaternary Fault Parameters, Ground Shaking, Liquefaction, and Earthquake-Induced Landslide Working Groups were held. Working groups discussed the previous year's work and revised 2003 long-term plans to identify partnerships and projects for future proposals. Final working group plans are available on the UGS Web site at geology.utah.gov. Over 150 people attended the Utah Earthquake Conference, and nearly 50 members attended the various working group meetings.

The Ground Shaking Working Group emphasized developing a "community velocity model" for use in developing detailed spectral-acceleration maps for ground motions at various periods that consider both shallow shear-wave velocities (Vs30) and deep-basin structure. The Liquefaction Working Group is implementing an existing NEHRP-funded pilot project in northern Salt Lake Valley. The Earthquake-Induced Landslide Working Group did not arrive at a consensus regarding future work or identify interested researchers. Because of this, the working group may not continue. The Utah Quaternary Fault Parameters Working Group coordinated its final meeting with the Earthquake Conference and other working group meetings, and developed consensus recurrence intervals and slip rates for various trenched faults. In addition, they set priorities for future paleoseismic studies.

Databases

To help working groups develop earthquake-hazards-mapping plans, the UGS updated three databases compiled in 2003: 1) shallow shear-wave velocities (Vs30), 2) deep-basin-structure data, and 3) geotechnical landslide shear strengths. All databases are in an interactive, searchable GIS format (HTML Image Mapper®, version 3.0). We also updated the Quaternary fault and fold database.

The shallow shear-wave-velocity database was updated to include 2004 spectral analysis of shear wave (SASW) data collected under another NEHRP-funded project. No new data were available for the deep-basin-structure database. The geotechnical landslide shear-strength database was updated from soil-test data from various sources, principally from geotechnical consultants and the Utah Department of Transportation. The Quaternary fault and fold database was updated with trenching and mapping data collected since compilation of Black and others (2003), and consensus values for recurrence intervals and slip rates for trenched faults determined by the Utah Quaternary Fault Parameters Working Group.

Fayette Segment Wasatch Fault Zone Mapping

We are mapping the geology of the Fayette segment of the Wasatch fault zone in central Utah, with an emphasis on the relations between surficial Quaternary deposits and faults. The Fayette segment is the southernmost segment of the Wasatch fault zone (figure 1), the longest active normal-slip fault in the western United States and the most active fault in Utah. This map is a continuation of our mapping of the Levan segment to the north and west (Hylland and Machette, 2004; figure 2), and extends 1:50,000-scale surficial-geologic mapping of the fault zone south of the five central segments that trend through the populous Wasatch Front area of north-central Utah.

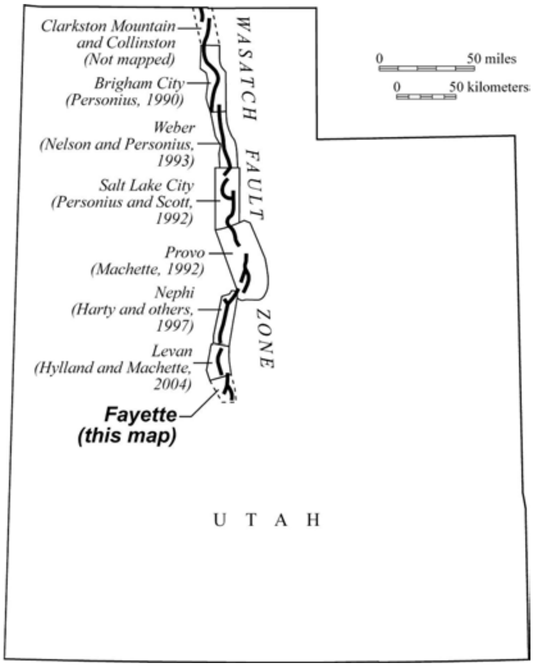

Figure 1. Index map of Wasatch fault zone in Utah, showing segments and existing 1:50,000-scale strip maps.

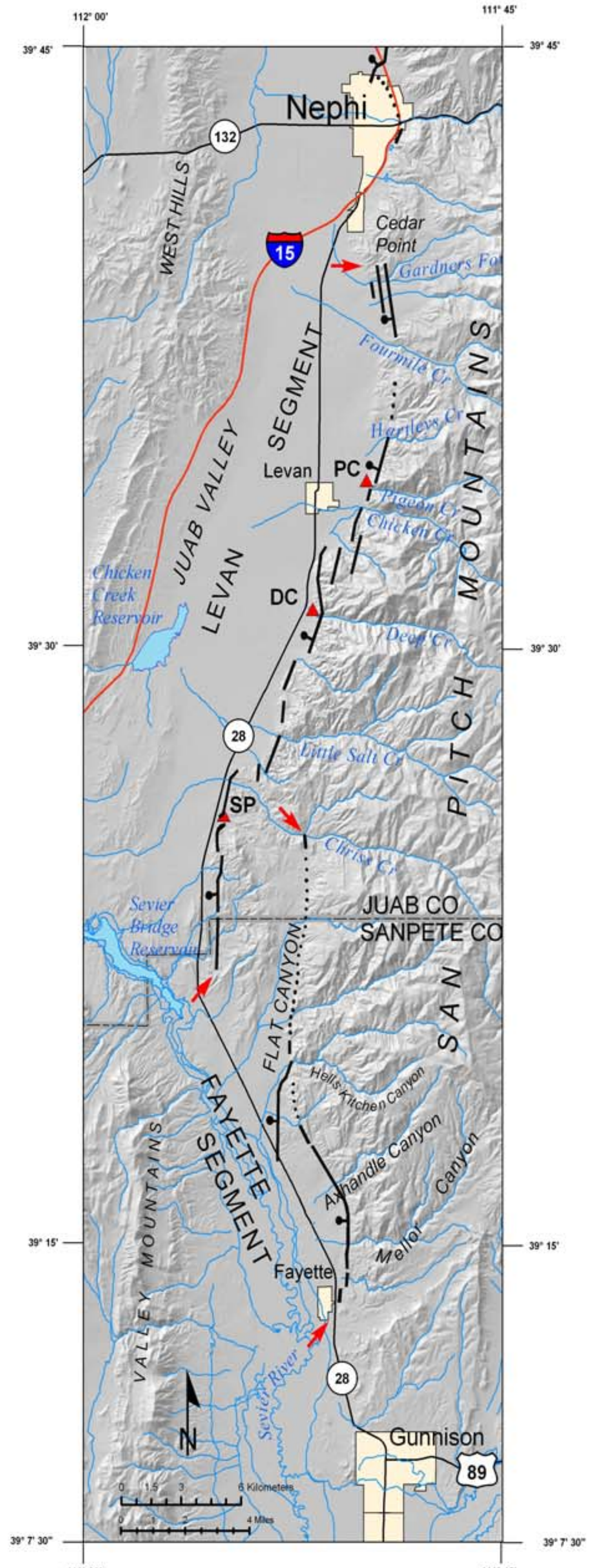

Figure 2. Levan and Fayette segments of Wasatch fault zone; faults shown by heavy lines, dotted where uncertain, bar and ball on downthrown side; arrows indicate approximate segment boundaries. PC (Pigeon Creek), DC (Deep Creek), and SP (Skinner Peaks trench) are sites discussed in Hylland and Machette (2004).

Our mapping has involved aerial-photograph interpretation (1:20,000) and field verification of fault scarps and surficial-geologic units along the fault zone, compilation of bedrock geology using published geologic maps, and age analysis of 21 scarp profiles; M.N. Machette (U.S. Geological Survey) measured 15 of these profiles in 1984, and we measured six more during the current project period.

The boundary between the Fayette and Levan segments consists of a zone of north- and north-northeast-trending fault scarps and lineaments on Quaternary-Tertiary alluvial-fan deposits and Quaternary basin fill within a 3.5-km-wide area between the two segments. These structures appear to accommodate a left-stepping transfer of displacement between the two segments. Although deposit ages in this area are poorly constrained, scarp morphology indicates an absence of Holocene faulting. At the southern end of the Fayette segment, fault scarps in Quaternary deposits end just east of the town of Fayette.

Late-Quaternary fault scarps of the Fayette segment comprise two strands that extend southward from Hells Kitchen Canyon. The eastern strand begins approximately 4 km south of Hells Kitchen Canyon and extends along the base of the San Pitch Mountains to the town of Fayette. We observed no fault scarps on Quaternary deposits along the range front north of Hells Kitchen Canyon. However, Machette and others (1992) suspected that the range front in this area is fault controlled. Also, at the north end of Flat Canyon, Weiss and others (2003) mapped Quaternary-Tertiary fan alluvium faulted down-to-the-west against Tertiary sedimentary strata. We believe Quaternary faulting has occurred along the northern projection of the eastern strand, but not in late Quaternary time. The western strand of the Fayette segment begins just south of the mouth of Hells Kitchen Canyon and extends southward approximately 6 km. The western strand crosses State Route 28, one of central Utah's major transportation routes for commercial and recreational traffic.

Unlike the Levan segment, late Holocene alluvial fans along the Fayette segment are unfaulted. This could be due to a difference between the two segments in age of most recent faulting, a difference between the Juab and northern Sevier Valleys in nontectonic factors that have influenced fan development, or both. Fault scarps on the Fayette segment include low (probably single-event) scarps cutting intermediate-level fan surfaces and stream terraces that range in age from latest Pleistocene to possibly middle Holocene. These scarps range in height from 1.3 to 2.9 m, and net vertical tectonic displacement (NVTD; determined from scarp-profile data) ranges from 0.8 to 1.6 m. Other fault scarps on the Fayette segment are high, multiple-event scarps cutting older (middle Pleistocene and older) alluvial-fan surfaces. These scarps generally range in height from 4.3 to 5.6 m, and NVTD generally ranges from 2.7 to 3.2 m. However, the scarp at the northern end of the western branch locally reaches a height of 20 m, and NVTD is at least 14 m. In general, scarp-height – slope-angle data for single-event scarps on the western trace plot younger (closer to the Fish Springs regression line of Bucknam and Anderson, 1979) than data for single-event scarps on the eastern trace (closer to the Drum Mountains regression line of Bucknam and Anderson, 1979). Clearly, the Fayette segment south of Hells Kitchen Canyon has undergone recurrent surface faulting during the late Quaternary, and in the absence of paleoseismic trench data and numerical age constraints on fan surfaces, Holocene faulting cannot be precluded.

In addition to new mapping of surficial geologic units along the fault zone, we extended our mapping to the west side of the Sevier River flood plain to encompass previously unmapped lacustrine deposits associated with the Bonneville highstand of latest Pleistocene Lake Bonneville, and some possible Quaternary faults. Unfortunately, the lacustrine deposits are all below the lowest elevation of Fayette-segment fault scarps, and cannot be used to constrain the timing of surface faulting.

Sevier/Toroweap Fault Paleoseismic Reconnaissance

We are making a reconnaissance of the Sevier/Toroweap fault in southwestern Utah (figure 3). Our goal is to identify sites where paleoseismic investigations may provide additional information on earthquake timing, recurrence, displacement, and vertical slip rate. Determining these paleoseismic parameters will allow us to more accurately characterize the Sevier/Toroweap fault's importance to the National Seismic Hazard Maps to determine the level of seismic hazard presented by the fault to southwestern Utah.

The Sevier/Toroweap fault is a left-lateral oblique-slip fault zone that extends from south of the Grand Canyon in Arizona to north of Panguitch, Utah, near the western edge of the Colorado Plateau. Although a continuous structure, by convention the fault is referred to as the Toroweap fault in Arizona and the Sevier fault (SF) in Utah. Pearthree (1998) divided the Toroweap fault in Arizona into three sections, the northernmost of which (Northern Toroweap section) he arbitrarily terminated at the Utah/Arizona border. Sargent and Philpott (1987) show the SF continuing in an uninterrupted manner northward from the border into Utah for an additional approximately 20 km before making a 2.5-km left step at Clay Flat about 6.5 km south of Mt. Carmel Junction, Utah (figure 3). Based on the presence of the left step and the apparent pull-apart basin formed there (Clay Flat), the *Quaternary Fault and Fold Database and Map of Utah* (Black and others, 2003) subdivides the SF in Utah into two sections: (1) an extension of Pearthree's (1998) Northern Toroweap section continuing from the Utah/Arizona border north to Clay Flat, and (2) the Sevier section extending for an additional 88 km (end to end) from Clay Flat to north of Panguitch (figure 3). In addition to the main SF, the *Quaternary Fault and Fold Database and Map of Utah* (Black and others, 2003) identifies two other groups of faults/folds near Panguitch (Sevier Valley [Hills Near Panguitch] Faults and Folds, and Sevier Valley [North of Panguitch] Faults) that are believed to be associated with the main SF (figure 1). This reconnaissance study includes both sections of the main SF in Utah and both fault and fold groups near the fault's north end.

Our reconnaissance includes aerial-photograph interpretation (chiefly 1:40,000-scale with 1:20,000-scale photos of select areas), field verification of fault features and

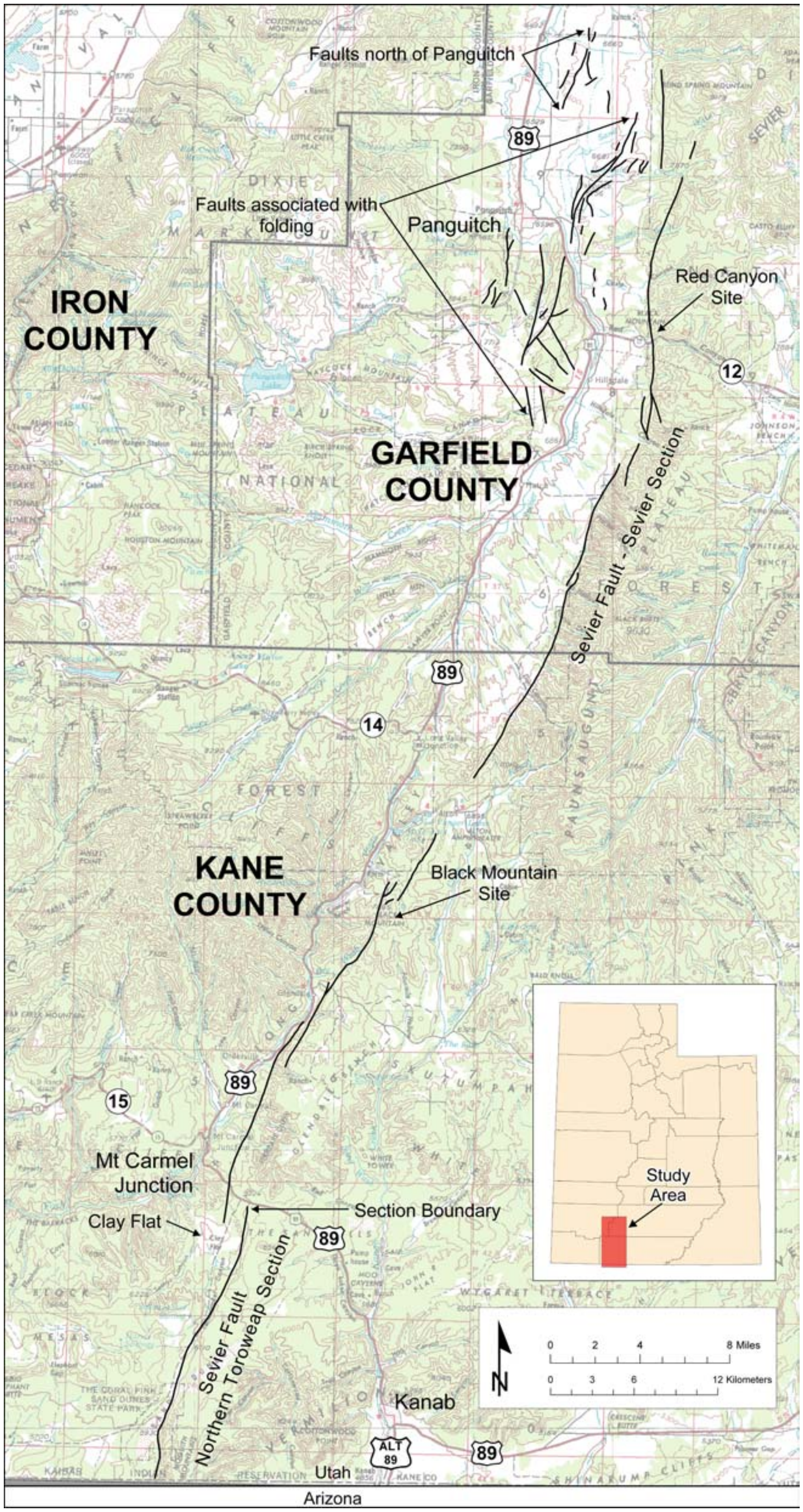

Figure 3. Sevier fault in southwestern Utah, showing the Northern Toroweap and Sevier sections, and associated faults near Panguitch.

related geologic units, geologic mapping of critical areas, and sampling of basalt flows for both $^{40}Ar/^{39}Ar$ radiometric dating and geochemical analysis to provide possible constraints on basalt correlation and fault timing and displacement.

Sevier fault main trace: To date, neither aerial-photograph interpretation nor field reconnaissance have revealed scarps formed on unconsolidated (Quaternary) deposits on either section of the main SF. Efforts continue to identify the oldest unfaulted basin-fill deposits that clearly overlie the fault to constrain the minimum age of most recent surface faulting.

Quaternary mafic flows: The SF displaces Quaternary basalt flows (Gregory, 1951; Cashion, 1967; Best and others, 1980; Anderson and Christenson, 1989) at two sites on the Sevier section of the fault. One site is at the mouth of Red Canyon immediately north of State Route 12 in Garfield County, and the other lies about a kilometer east of U.S. Highway 89 in northern Kane County (figure 3). Both locations are identified on USGS topographic maps as "Black Mountain." For clarity, we refer to the Garfield County location as the "Red Canyon" site, and the Kane County location as the "Black Mountain" site. Best and others (1980) used K-Ar radiometric methods to date the Red Canyon and Black Mountain flows at 0.56 ± 0.07 Ma and 0.52 ± 0.06 Ma, respectively. Anderson and Christenson (1989) report 200 m of vertical displacement at Red Canyon, and Cashion (1967) reports 75 feet (23 m) of vertical displacement at Black Mountain, although Anderson and Christenson (1989) dispute this figure for a variety of reasons. Anderson and Christenson (1989) report a tentative slip rate since the late middle Quaternary of 0.36 mm/yr for the SF at Red Canyon.

We have submitted samples from both sites for $^{40}Ar/^{39}Ar$ radiometric dating (New Mexico Bureau of Mines and Mineral Resources Argon Laboratory) to verify and possibly improve the age estimates of Best and others (1980), and also have submitted samples for geochemical analysis (Washington State University GeoAnalytical Laboratory) to establish correlations across the fault. Detailed geologic mapping will be performed at both sites to clarify/confirm the vertical displacement in the flows. Once the vertical displacement and age of the basalts are better characterized, we will calculate a long-term slip rate for the SF at both locations. We have also submitted samples from a basalt outcrop identified by Gregory (1951) on a ridge top high in the Sunset Cliffs in the footwall of the SF for radiometric dating and geochemical analysis. We believe this basalt may predate formation of the Sunset Cliffs and therefore initiation of faulting on the northern SF, and should provide a maximum limiting age on the initiation of faulting in that area.

Faults and folds in unconsolidated deposits near Panguitch: An extensive zone of broad anticlines and synclines and related extensional normal-slip fault scarps, many forming narrow grabens, occupies the hills immediately south of Panguitch and disrupts broad, gently sloping alluvial surfaces flanking the high bedrock scarp of the SF (Sunset Cliffs) east of Panguitch (Anderson and Christenson, 1989; Moore and Straub, 1995; Kurlich and Anderson, 1997). Deformed deposits range in age from Mio-Pliocene to possibly late Pleistocene (Anderson and Christenson, 1989). The fault scarps are conspicuous on aerial photographs and range from less than a meter to more than 25 m high. Additionally, a zone of short northeast-trending normal faults north of Panguitch bounds a conspicuous horst (Anderson and Rowley, 1987; Anderson and Christenson, 1989). Scarps there are as high as 12 m and displaced surfaces may be as old as middle Pleistocene (Anderson and Christenson, 1989), while a likely most recent earthquake scarp less than a meter high is formed on an alluvial surface of probable middle to late Pleistocene age. Anderson and Christenson (1989) photo-logged a fault exposure in the wall of a wood-chip disposal pit that intersects the low scarp and report evidence for two surface-faulting earthquakes, the most recent of which is likely late Pleistocene in age.

Our field reconnaissance showed that many other scarps and associated grabens in the Panguitch area have good access and are amenable to trenching. The age of the faults and folds is not known, but the wide range in scarp heights implies a similar wide range in age and multiple surface-faulting earthquakes. An anomaly in the channel pattern of the Sevier River where it crosses the axis of the fold and fault belt southeast of Panguitch indicates possible active uplift (Anderson and Christenson, 1989; Jorgensen Harbor, 1998). However, while acknowledging that these faults and folds likely have a genetic relation to the subparallel SF, the nature of that relation is not clear, nor is the relevance of any paleoseismic data that might be obtained from trenching these features to the main SF.

REFERENCES

Anderson, J.J., and Rowley, P.D., 1987, Geologic map of the Panguitch NW quadrangle, Iron and Garfield Counties, Utah: Utah Geological and Mineral Survey Map 103, 8 p. pamphlet, scale 1:24,000.

Anderson, R.E., and Christenson, G.E., 1989, Quaternary faults, folds, and selected volcanic features in the Cedar City $1^{o}x2^{o}$ quadrangle, Utah: Utah Geological and Mineral Survey Miscellaneous Publication 89-6, 29 p.

Best, M.G., McKee, E.H., and Damon, P.E., 1980, Space-time-composition patterns of late Cenozoic mafic volcanism, southwestern Utah and adjoining areas: American Journal of Science, v. 280, p. 1035-1050.

Black, B.D., Hecker, S., Hylland, M.D., Christenson, G.E., and McDonald, G.N., 2003, Quaternary fault and fold database and map of Utah: Utah Geological Survey Map 193DM, scale 1:50,000, compact disk.

Bucknam, R.C., and Anderson, R.E., 1979, Estimation of fault-scarp ages from a scarp-height – slope-angle relationship: Geology, v. 7, p. 11-14.

Cashion, W.B., 1967, Geologic map of the south flank of the Markagunt Plateau, northwest Kane County, Utah: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-494, scale 1:62,500.

Gregory, H.E., 1951, The geology and geography of the Paunsaugunt region, Utah: U.S. Geological Survey Professional Paper 226, 116 p., 4 plates in pocket.

Harty, K.M., Mulvey, W.E., and Machette, M.N., 1997, Surficial geologic map of the Nephi segment of the Wasatch fault zone, eastern Juab County, Utah: Utah Geological Survey Map 170, 14 p., scale 1:50,000.

Hylland, M.D., and Machette, M.N., 2004, Interim surficial geologic map of the Levan segment of the Wasatch fault zone, Juab and Sanpete Counties, Utah, *in* Christenson, G.E., Ashland, F.X., Hylland, M.D., McDonald, G.N., and Case, B., Database compilation, coordination of earthquake-hazards mapping, and study of the Wasatch fault and earthquake-induced landslides, Wasatch Front, Utah: U.S. Geological Survey, National Earthquake Hazards Reduction Program Final Technical Report, award no. 03HQAG0008, variously paginated, map scale 1:50,000.

Jorgensen Harbor, D., 1998, Dynamic equilibrium between an active uplift and the Sevier River, Utah: Journal of Geology, v. 106, p. 181-194.

Kurlich, R.A., III, and Anderson, J.J., 1997, Geologic map of the Hatch quadrangle, Garfield County, Utah: Utah Geological Survey Miscellaneous Publication 97-5, 17 p. pamphlet, scale 1:24,000.

Machette, M.N., 1992, Surficial geologic map of the Wasatch fault zone, eastern part of Utah Valley, Utah County and parts of Salt Lake and Juab Counties, Utah: U.S. Geological Survey Miscellaneous Field Investigations Series Map I-2095, scale 1:50,000.

Machette, M.N., Personius, S.F., and Nelson, A.R., 1992, Paleoseismology of the Wasatch fault zone – A summary of recent investigations, interpretations, and conclusions, *in* Gori, P.L., and Hays, W.W., editors, Assessment of regional earthquake hazards and risk along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper 1500-A, 71 p.

Moore, D.W., and Straub, A.W., 1995, Preliminary geologic map of the Panguitch quadrangle, Garfield County, Utah: U.S. Geological Survey Open-File Report 95-9, 13 p. pamphlet, scale 1:24,000.

Nelson, A.R., and Personius, S.F., 1993, Surficial geologic map of the Weber segment, Wasatch fault zone, Weber and Davis Counties, Utah: U.S. Geological Survey Miscellaneous Field Investigations Series Map I-2199, scale 1:50,000.

Pearthree, P.A., compiler, 1998, Quaternary fault data and map for Arizona: Arizona Geological Survey Open-File Report 98-24, 122 p., one plate in pocket, scale 1:750,000, 1.4 Mb disk.

Personius, S.F., 1990, Surficial geologic map of the Brigham City segment and adjacent parts of the Weber and Collinston segments of the Wasatch fault zone, Box Elder and Weber Counties, Utah: U.S. Geological Survey Miscellaneous Field Investigations Series Map I-1979, scale 1:50,000.

Personius, S.F., and Scott, W.E., 1992, Surficial geologic map of the Salt Lake City segment and parts of adjacent segments of the Wasatch fault zone, Davis, Salt Lake, and Utah Counties, Utah: U.S. Geological Survey Miscellaneous Field Investigations Series Map I-2106, scale 1:50,000.

Sargent, K.A., and Philpott, B.C., 1987, Geologic map of the Kanab quadrangle, Kane County, Utah and Mohave and Coconino Counties, Arizona: U.S. Geological Survey Geologic Quadrangle Map GQ-1603, scale 1:62,500.

Weiss, M.P., McDermott, J.G., Sprinkel, D.A., Banks, R.L., and Biek, R.F., 2003, Geologic map of the Chriss Canyon quadrangle, Juab and Sanpete Counties, Utah: Utah Geological Survey Map 185, 26 p., scale 1:24,000.

NON-TECHNICAL SUMMARY

The UGS held the 2004 Utah Earthquake Conference and Working Group meetings, co-sponsored by the USGS and Utah Seismic Safety Commission. Results of 2003 work were presented at the conference and discussed in working group meetings. The earthquake-hazard mapping plans developed in 2003 were revised and updated to define data needs and establish partnerships for proposed 2005 projects. In support of this effort, the UGS updated databases compiled in 2003. We extended the surficial geologic mapping of the Wasatch fault to the south to include the Fayette segment in central Utah, and performed reconnaissance paleoseismic studies of the Sevier/Toroweap fault in southwestern Utah to identify sites for future detailed studies.

REPORTS PUBLISHED

All working group plans are posted at the UGS Web site (geology.utah.gov). We plan to have the combined Levan and Fayette segment surficial geology map available as a UGS Open-File Report by March 2005. Results of all 2003 studies were presented at the February 26, 2004, earthquake conference; results of 2004 studies will be presented working group meetings in Salt Lake City in February 2005.

AVAILABILITY OF DATA

The updated shallow shear-wave-velocity, deep-basin-structure, and geotechnical landslide shear-strength databases (HTML Image Mapper®, version 3.0) are available from Greg McDonald, 801-537-3383, email gregmcdonald@utah.gov. The updated

Quaternary fault and fold database will be available at the UGS Web site (geology.utah.gov) in 2005.